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A machine and a method therefor

TECHNICAL FIELD

The present invention relates to a rotating electric machine comprising a stationary part, stator, and a rotatory part, rotor, which is fixedly journalled in relation to the stator. More precisely, the invention relates to a rotating electric machine which exhibits a stator, the internal limiting surface of which deviates from the circular cylindrical surface. The rotating electric machine is intended to be manufactured for a plurality of power ranges and for both low voltage and high voltage. Preferably, the machine is intended to be connected to a power network and, in particular, the machine is intended to be utilized for large powers and high voltages. In the following text, the term rotating electric machine means such a rotating electric machine which transforms electrical energy into mechanical energy and vice versa. Thus, the rotating electric machine may be a motor as well as a generator.

BACKGROUND ART

The majority of known rotating electric machines comprise a cylindrical rotor which rotates in a stator with a cylindrical inside. To obtain a considerable torque, a rotor with a large diameter is chosen and to obtain a greater acceleration, a longer rotor with a smaller diameter is chosen. The speed of rotation and the strength in the material at the outer layer of the rotor often limit the diameter of the rotor. The reason for the cylindrical shape of the stator is primarily that the manufacture of an associated stator is so much simpler if it is designed cylindrically. The fact that the rotor rotates implies that only rotationally symmetrical shapes are conceivable for the inside of the stator. Likewise, only poles which touch one and the same conceived cylinder, housed in the stator, are possible for the rotor. The space between the inside of the stator and the mentioned cylinder housed therein is designated air gap.

The typical appearance of an ordinary rotating electric machine is based on historical reasons. The rotor and the stator are usually manufactured separately. To be able afterwards to join together the two bodies and obtain an even air gap, only two alternative shapes are available: cylindrical or conical. A design according to the conical shape has several disadvantages in relation to the cylindrical shape and has not found any commercial use other than as a brake motor. The currently most commonly used type of a rotating electric machine is, therefore, the cylindrical one. Today's winding technology implies that winding coils are placed in slots in the stator or the rotor. When manufacturing a motor for high voltage, the coils are first wound onto fixtures, whereupon they are provided with an insulation. The coils are often subsequently treated in an autoclave for driving out air bubbles and for curing the insulation. The thus "finished" coils are pressed down into the slots and secured by wedges. Finally, the coil ends are jointed to each other to form complete windings.

In accordance with established production engineering for large rotating electric machines, the stator core, and often also the rotor, are composed of laminated steel sheet. The laminated sheets, which may be magnetically oriented, are stacked in the axial direction to reduce losses caused by eddy currents. To pile up a stator for such a rotating electric machine thus comprises building up the stator on edge. Each layer consists of a plurality of punched-out sheets, which constitute part of a circular segment and which together form an axial layer of a hollow cylinder. The sheets contain punched-out portions which, when the stator is completed, form slots to receive the winding. Between the slots, teeth are formed, the tip portions of which constitute the inner limiting surface of the stator.

However, an evaluation of Maxwell's equations shows that shapes of the rotor and the stator which deviate from the cylindrical shape could entail a more

efficient utilization of the induced forces. A rotating electric machine, the rotor of which is rounded at the short ends and the stator of which is drawn down over the rounded portions of the rotor could thus result in a rotating electric machine with higher efficiency. From what is stated above it is realized that this would also entail a completely new approach and certainly a completely new mode of working for manufacturing a rotating electric machine.

A so-called "Spherical motor" is described in the specialist literature and in certain patent documents. The expression indicates that it would relate to a motor, the rotor of which has a spherical shape and rotates around a shaft. However, instead it is a question of an operating device for an industrial robot or the like, where it is desired to provide a movement in three degrees of freedom around one and the same point. Such an operating device is described in patent document US 5,410,232. In the operating device shown, the shaft fixed to the rotor is not primarily intended to rotate but rather intended to be moved in a controlled manner such that it "points" in different directions. Another operating device of this kind is described in patent document US 5,413,010. The task of the shown motors is thus not primarily to rotate but to constitute an operating device which directs an operating arm in different directions. In the examples shown, it is thus not a question of a rotating electric machine, where the rotor rotates with one degree of freedom, but a motor which, in a controlled manner, may rotate its shaft in different directions around a common point.

Additional examples of a so-called "Spherical motor" are disclosed in patent documents US 4,739,241 and US 4,661,737. In these cases, it is a question of a motor, known per se, with a rotating shaft which is fixed to a suspension system. The suspension permits the rotary shaft to be rotated, in a controlled manner, in various directions around a centre.

Another example of a rotating motor, the rotor of which deviates from the circular-cylindrical shape are pump motors. In these applications, such a rotor is often almost spherical. One half houses an impeller which implements kinetic energy to the liquid passing through. The other half contains the rotor itself, which is brought to rotate by magnetic forces from a similarly hemispherical stator. The magnetic field between the rotor and the stator is unbalanced, which results in unwanted axial forces acting on the axle bearing. Usually, a rotor for such a pump motor does not rotate around a stationary shaft, but instead the rotor is journalled on a ball, which eliminates a shaft bearing which has to be sealed and which allows the rotor to "wag" to a certain extent around a centre. Examples of a pump motor of the kind described are shown, for example, in patent documents US 4,580,335 and in US 4,352,646.

A rotating electric machine with a rotor in the form of a thick slice cut out from a sphere is previously known from an article in Electrical Times, 9 June 1960, "Design of Spherical Motors", by E. R. Laithwaite. The motor discussed in the article has an associated stator which, with an air gap of even thickness, is attached to the rotor. The stator is made from radially arranged plates with punched-out pockets, which form slots for the stator winding. The stator is arranged rotatable around an axis which perpendicularly intersects the rotor shaft, such that parts of the stator may be turned outside the rotor. The stator winding is angled in relation to a plane intersecting its axis. By turning the stator, the induction forces are reduced and the rotor and stator windings are angled in relation to each other. The task of the machine shown is to achieve a possibility of controlling speed and torque by turning the stator.

From patent document US 5,204,570, a rotating electric machine is known, the rotor of which deviates from the cylindrical shape. The object of the machine is to manufacture a miniaturized motor for use where the smallest building volume is at a premium. As examples of use of such a machine, a motor for fans and a motor for driving disc or tape recorders are stated. The machine is

said to be inexpensive and still surprisingly efficient, even when being manufactured in miniaturized form. The machine has a rotor in the form of a spheroid comprising one or more permanent magnets. The stator comprises spirally wound coils, the axes of which intersect the motor shaft. The coils have no iron core and are slightly curved. It is stated in the document that in relation to weight it is advantageous to use air-wound coils as stator. The manufacture of a laminated iron core is said to be expensive owing to expensive tools and, in addition, eddy-current losses are obtained.

To collect the magnetic field on the outside of the stator, a dome-shaped shell of ferromagnetic material is connected to the rotor. The fact that this dome rotates together with the rotor means that no eddy-current losses arise. However, in practice the dome constitutes a disadvantage since the motor in this way has an outer limitation which rotates.

At least at higher powers, the stator winding generates large quantities of heat which have to be cooled away. From the air-wound coil, heat can only be discharged by convection into the surrounding air. For an efficient cooling, however, the surrounding air must circulate such that cold air permanently circulates around the coil. This causes the dome arranged outside to prevent the surrounding air from circulating. In this way, the cooling becomes exceedingly inefficient and probably results in the insulating material of the winding melting, with an ensuing short circuit. For an effective cooling, a heat carrier is usually required, which is in thermal contact with the winding and which efficiently carries away heat for cooling by a cooling agent. Metal is such a heat carrier.

SUMMARY OF THE INVENTION

The object of the invention is to suggest methods for the manufacture of a rotating electric machine which, in a more efficient way than previously known, utilizes the induction forces between the rotor and the stator. The rotating electric machine, which may be a motor as well as a generator, shall be cost-efficient and be capable of being manufactured for high as well as low voltage ranges within a wide power range. In comparison with a conventional machine for the same power range, the machine in question shall permit a considerable saving of material, both with regard to the stator and rotor cores as well as with regard to winding material. The machine in question shall also be capable of being manufactured with a greater efficiency than a conventional machine of the same size. The machine shall also be capable of efficiently carrying off heat generated in the machine.

The rotating electric machine shall be capable of being manufactured for low as well as high power ranges. Among the fields of use which the machine is intended to cover within the high-voltage range are primarily hydro- and turbogenerators which may be directly connected to a high-voltage network for 36 kV or a higher voltage. In such applications, the machine shall be capable of being manufactured for powers higher than 10 kW. Also machines for connection to a power network shall be capable of being manufactured. Within the low-voltage range, there are examples of a plurality of fields of use where an energy-saving machine according to the invention may be utilized as a motor or a generator. Thus, the machine may be used as a generator in conveyances which are driven by an internal-combustion engine. It may also be used as a drive means for a conveyance. The concept conveyance in this connection is to be interpreted in a broad sense. The word conveyance includes vehicles for ground transport on roads or on rails as well as craft for travelling in space and in water. Another field of use within the low-power range for a machine according to the invention is as a prime mover in electrical

domestic appliances as, for example, refrigerators and freezers, vacuum cleaners, kitchen machines, etc.

This and other objects are achieved with a rotating electric machine with the characteristic features described in the characterising portion of the independent claims 1, 17 and 19 and with a method with the characteristic features described in the characterizing portion of the independent claims 12 and 16. Advantageous embodiments are described in the characterizing portions of the dependent claims.

The rotating electric machine in question, which in the following text is referred to as a motor, a generator or a machine, has a stator comprising a core of a magnetizable material, the inner limiting surface of which has a rotationally symmetrical shape which, in at least some part, exhibits a cup shape. By a magnetizable material is to be understood a material which has a relative permeability which is greater than one. The inner limitation of the stator may thus comprise a cavity defined by a solid of revolution formed by rotation of a curve. Such curve has a continuous rate of change, which, in at least the end parts, is different from zero. Likewise, the rotor deviates from a circular-cylindrical body and may have the same shape as the inner limiting surface of the stator, such that an air gap with a substantially even thickness is formed between the rotor and the stator. It is essential for the machine in question that an active magnetic field is directed three-dimensionally towards the centre of the rotor. Such an active magnetic field would intersect the stator winding substantially at right angles and surrounds the rotor, or at least parts of the rotor, in a cup-shaped manner.

While a traditionally cylindric type motor has an active magnetic field formed as a wedge the magnetic field of the motor in question has conical or pyramidal form. The cup-shaped magnetic field thereby amplifies the induction forces between the stator and the rotor. The magnetic field

according to the present invention could be described as containing magnetic vectors, having an active component parallel to the rotor axle and pointing towards the centre of the rotor. When the magnetic field is in balance the sum of the components parallel to the axle is zero. The most efficient embodiment would seem to be a machine with a stator which has a spherical inner limiting surface, in which a spherical rotor rotates. The difficulty of designing the stator winding close to the shaft of the machine, however, indicates that other solids of revolution may be preferable.

The common shape which is aimed at in both the rotor and the stator is achieved by a so-called spheroid. A spheroid is a surface generated when an ellipse rotates around one of its symmetry lines. It may thus have both an oblate, flattened, and a prolate, extended, shape. As the ellipse includes the circle the spheroid includes the sphere. The common rotational shape is not, however, limited to a spheroid but may be composed of several solids of revolution. Thus, the invention also comprises a circular cylinder with half a spheroid attached to each end thereof. In certain applications, the shape may be determined by the practical arrangement of the stator winding.

A machine according to the invention may be wound in a plurality of different ways, both as regards the rotor and the stator. Each winding type which is used in a conventional machine may also be applied to a machine according to the invention. The rotor thus also comprises a squirrel-cage winding whereas both the stator and the rotor comprise both a lap winding and a wave winding. The machine may also be wound for connection to a power network. This comprises, among other things for alternating current, such single-phase and polyphase windings for both the rotor and the stator as are normally used for conventional machines. A conventional machine in this context means a machine with a cylindrical rotor and a stator with a corresponding cylindrical inner limiting surface.

In the same way as for conventional machines, slots for receiving a winding are arranged in the rotor and/or the stator in the machine in question. In conventional machines, this is commonplace, since in these machines the winding slots are straight. In the machine referred to here, the slots are curved, and therefore normal winding technology cannot be applied in a simple manner. The winding is thus not suitable for manufacture in a fixture for subsequent placement in the slots. In the machine in question, the winding most likely has to be wound "in situ". To this end, the winding may advantageously be manufactured from a cable. By cable is to be understood here a flexible, insulated electric conductor, which may contain several conductor strands.

For direct connection to a high-voltage network, a machine according to the invention is adapted to comprise a winding of a high-voltage cable. Powers of up to 10 MW or more may thus be obtained. Such a cable usually comprises a semiconducting even layer around the conductor which may be divided into strands. The semiconducting layer is intended to distribute the electric field strength such that no field concentrations arise which may cause a flashover. Such a cable may also comprise a semiconducting layer surrounding the insulation and intended to contain the electric field in the cable. Usually, the outer semiconducting layer is connected to ground. A suitable cable and a suitable method of manufacturing the winding in question for high voltage are described in patent document WO 97/45919.

In a conventional machine with a cylindrical rotor which rotates in a cylindrical stator, the end walls constitute ineffective surfaces. No effective magnetic fields are created here but instead leakage fields, which deteriorate the efficiency, arise here. To joint the coils using the conventional winding technology, a large volume is required at the end pieces of the stator. The space-demanding coil ends also imply that the bearing locations for the rotor shafts will be situated far away from the centre of the rotor. This results in an

increased risk of unbalance of the rotor, in which case the bearings must be oversized. It is then realized that the end walls of a traditional machine entail both a lower efficiency and a lower utilization of the total volume of the machine. Rounding of the end walls of the rotor and surrounding the stator in a cup-shaped manner would thus seem to be advantageous. In this way the entire rotor is surrounded by a concentrated magnetic field, whereby the efficiency of the machine may be increased.

It may be demonstrated that a rotating electric machine according to the invention possesses advantages in relation to a conventional machine with only a cylindrical rotor and a corresponding stator. Based on the volume of a rotor associated with a conventional machine, the weight of a machine according to the invention may be reduced by about 30% in spite of the fact that the machine yields the same power. For a machine according to the invention with the same weight as a conventional machine, the machine in question may yield about 50% more power.

If a conductor loop surrounds a magnetic flux which varies in time, a voltage, electromotive power, is induced in the loop. The voltage which is induced is described by the product of the number of turns in the loop and the time rate of change of the magnetic flux. The magnetic flux is dependent on the magnetic field multiplied by the area of, for example, the field enclosed in the stator winding. Since the magnetic field is dependent on the material, it is realized that the area is the sole variable. When optimizing the area in relation to the circumference, a surface of a circle, or rather a sphere, is obtained since a volume is formed during rotation of a loop. This implies that the rotor should be spherical and that the inner surface of the stator shall describe a sphere.

For a conventional machine, the coil ends constitute a problem area. In a machine according to the invention, there are practically no coil ends. The

losses in the end regions of the machine will thus be considerably lower than the corresponding losses for a conventional machine

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be explained in greater detail by description of an embodiment with reference to the accompanying drawings, wherein

Figure 1 shows half a cross section of a rotating electric machine according to the invention,

Figure 2 shows, in a longitudinal section, the principle of one embodiment of such a machine,

Figure 3 shows a stator element cut out from a machine according to the invention,

Figure 4 shows a part cut out from the stator element, and

Figure 5 shows three different shapes (a, b and c) of a rotor associated with a rotating electric machine according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The rotating electric machine shown in Figure 1 has a rotor 1 and a stator 2. The rotor is adapted to rotate with one degree of freedom in relation to the stator. The stator is composed of, for example, laminated sheets which may be magnetically oriented to a core which surrounds the rotor. The stator is made with a plurality of teeth 3 and an equally large number of stator slots 4. A plurality of insulated conductors 5, which may comprise a plurality of conductor strands, are arranged in the stator slots. In the example shown, the winding is made from a cable and the machine shown is intended to be used at

high voltage. The conductors together form one or more main windings. At the furthest end in a radial direction, a plurality of smaller, insulated conductors 6 are arranged, which in the example shown are adapted to constitute a winding for auxiliary power or other voltage, such as in a so-called multi-voltage machine which is connected to a plurality of voltages.

Figure 2 is an embodiment showing the principle of a rotating electric machine according to the invention. A rotor 1 is fixed to a rotor shaft 7 around which it rotates. The rotor is surrounded by a stator 2,which is made of a magnetizable material, for example soft iron which may be magnetically oriented. The stator has an inner cavity 9 which surrounds the rotor 1 and the outer surface of which constitutes the inside of the stator. In the example shown the cavity is limited by a sphere. The outside of the stator is limited by a spheroid. In the example shown, the surface is formed from an ellipse which rotates with its shorter symmetry line coinciding with the rotor axis. The outside of the stator may, however, have an arbitrary shape. The rotor is a solid of revolution which, in the example shown, also has a shape which is limited by a spheroid. In the example shown, both the stator and the rotor are limited by surfaces of revolution, the symmetry axes of which coincide. The symmetry axes may, however, also cross each other.

The figure also schematically shows four stator winding 8, which penetrate the stator core. Three of the windings leave the stator core at the rotor ends whereas one is enclosed in the stator. The stator winding is threaded through slots in the stator core. A comparison between cross sections through the stator in a normal plane to the rotor axis shows that the largest cross-section diameter is obtained in a normal plane to the centre of the rotor axis. The cross-section diameter then decreases towards the ends of the stator. In the example shown, also the cross-section area of the stator decreases towards the ends. However, the winding area is constant through all the cross sections, so the proportion of core area decreases towards the ends. It is thus realized that,

at some distance from the central normal plane, the core area between the winding turns ceases. At this distance from the central normal plane, the windings may be disposed in the same slots or be placed across one another. At some further distance from the symmetry plane, only the winding area remains, and therefore the windings here leave the stator core and pass into the open. On the other side of the rotor shaft, the windings again penetrate in the same way into the stator core. To illustrate the winding technique more closely, it may be compared to winding a ball which is rotated in one degrees of freedom only. This implies that a winding turn lies in a plane which intersects the rotor axis.

Figure 3 shows a stator element 10 cut out from a stator, which stator element constitutes a body which is obtained at two plane mutually intersecting sections through a hollow sphere, whereby the intersection line coincides with a symmetry line through the hollow sphere. To better illustrate the appearance of the body, it may be likened to a slice cut out from, for example, a melon. The stator element is limited by an inner cup-shaped surface 11, which coincides with the cavity 9, and an outer surface 12 (concealed) which is bulging. In the lateral direction, the body is limited by a first side 13 which is a plane and a second side 14 (concealed) which is also plane. The stator element is oriented with its longest extent in a plane coinciding with the rotor axis. To provide space for the rotor shaft, a first cupped chamfer 15 and a second cupped chamfer 16 are arranged in the stator element in the edge line between the first side and the second side. The figure also shows the contour of a part 17 which is integrated into the body and which is described in more detail in Figure 4.

Figure 4 shows a piece of the core, 17, cut out from a stator element belonging, for example, to a low-voltage machine. For the sake of clarity, the cut-out core piece may be conceived to be cut out from the stator element in Figure 3, as indicated by the dashed line. The core piece is limited in the lateral direction

by four plane sections which all intersect the same point, such that the core piece is accommodated in a truncated pyramid. The four plane sections constitute only conceived limiting planes for the cut-out core piece and shall only show the three-dimensional shape. A continuous passage 18 is provided through the core piece and is adapted to receive a winding (not shown). The side of the hole connects with an opening 19 which separates a first tooth 20 and a second tooth 21 as well as a back portion 25 positioned therebetween. The core body is limited inwardly by a first tooth surface 22 and a second tooth surface 23, which are both cup-shaped and, on the outside of the back portion, by an envelope surface 24 (concealed) which is bulging.

When activating a loop, arranged through the hole 18, a magnetic field is generated through the core piece. From a rotor (not shown) which is positioned immediately in front of the teeth, the magnetic field is directed vertically against the first, cup-shaped tooth surface 22. In the core piece, the magnetic field then follows the tooth in a radial direction, the back portion in a tangential direction and then along the outer part of the stator. When the magnetic field reaches a second, cup-shaped tooth surface, the field passes in a direction vertically out from the second tooth surface towards the rotor, in which the field is closed.

The area of the magnetizable material through which the field penetrates should in each section be equally large. For a three-dimensionally curved stator, which is represented by the core piece in Figure 4, the larger width at the back portion compensates for the distance between the edge and the hole. The cut surfaces indicated by dashed lines in the figure are intended to show this fact. Thus, it is realized from the figure that the first tooth surface 22 has the same size as a first cut surface 26 on a level with the largest width of the passage 18. Finally, it is realized that this area also corresponds to a second cut surface 27 placed at the back portion and which has an extent directed opposite to the first tooth surface. The three-dimensional curvature therefore

implies that material may be saved, especially in the back portion of the stator, and that the stator may be made smaller.

The rotor belonging to the machine may have a plurality of different shapes. Figure 5 shows three examples of a rotor comprised in a machine. Figure 5a shows a rotor with a ball shape whereas Figure 5c shows a rotor in the form of a spheroid. In the example shown, the spheroid is prolate, that is, extended. Figure 5b, finally, shows a composed shape, which exhibits a cylindrical mid-portion connected at each end to half a spheroid.

To carry off heat generated in the machine, cooling channels (not shown) for a cooling agent can be arranged in the stator core. The machine shown in the example is wound with a high-voltage cable containing a plurality of strands. Such a cable is completely insulated and therefore contains, inside the insulation, the entire voltage potential. This is advantageous when, for example, cooling the machine since the stator is connected to ground potential. In this way, thus, also the cooling agent may be maintained at ground potential. Another great advantage with the wound cable is that the windings may freely cross each other and even make contact with each other in the end regions of the machine.

The present invention is not limited to the machines shown in the embodiments. The shape of the rotor and the stator may thus vary within a very wide range. Common to all of them, however, is that the stator core surrounds the rotor in a cup-shaped manner such that a three-dimensionally directed magnetic field is formed around the rotor. Nor is the invention limited to comprise only a winding disposed in slots in the stator. The winding may thus also be arranged as a so-called air-gap winding. Nor must a winding for a machine according to the invention be arranged in a direction which coincides with the motor or stator shaft. Parts of the winding may thus be arranged in a free pattern along the curved stator and may thus represent both

straight slots and slots crossing the rotor axle. Also, the shafts of the rotor and the stator do not have to coincide but a machine with crossing shafts is also comprised in the invention.

A motor according to the invention can also comprise permanent magnets in either the rotor or the stator.